LESSON 9

TOPIC 3

Construction Monitoring and Quality Assurance – Pile Load Testing

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 3
Pile Load Testing

Slide 9-3-1

Header

CONSTRUCTION MONITORING AND QUALITY ASSURANCE - Pile Load Testing

1. Relate Pile Load Testing to Design Goals and Cost Savings
2. Interpret Pile Failure Load

ACTIVITIES: Question-Answer
Davisson's Method

Slide 9-3-2

Objectives.

Slide 9-3-3

Funny Slide indicating designers frequently cannot decide on pile length or capacity so they "vote".

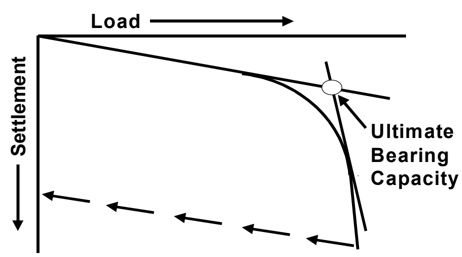
Pile Load Testing

Pile Load Testing is the Most Positive Method of Determining Pile Capacity.

Slide 9-3-4

Introduce the reason for pile load testing.

Load - Settlement Graph



Slide 9-3-5

Show a typical load test plot and interpreted failure load. Use this as the lead to different test procedures may require different interpretation methods for failure.

Types of Load Tests

Routine

- ***Static***
- ***Dynamic***

Recently Developed

- ***Osterberg Cell***
- ***Statnamic***

Slide 9-3-6

Overview the test types to be covered in the lesson. Differentiate between the common methods and the new methods.

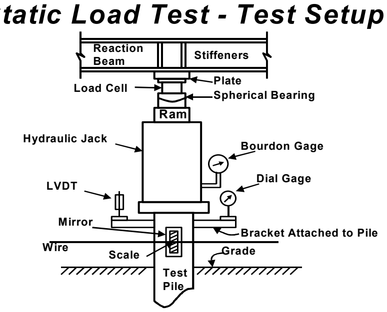
Static Load Test Types
ASTM D1143

- *Maintained Load*
- *Quick Load (Texas Quick Test)*
- *Constant Rate of Penetration (CRP)*

Slide 9-3-7

Overview static load test methods and emphasize that the procedures for these are covered under ASTM.

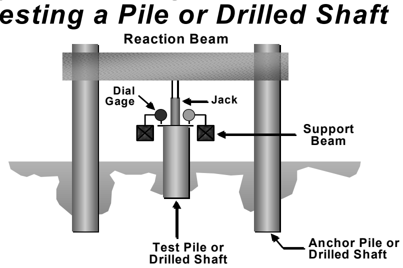
Static Load Test - Test Setup



Slide 9-3-8

The purpose of this slide is to show that the test setup needs to be done by experienced personnel. The amount of test equipment is large and proper placement of instruments critical to the success of the test. In addition the safety of the workers must be respected as loads applied are often very large.

Typical Arrangement for Load Testing a Pile or Drilled Shaft



Slide 9-3-9

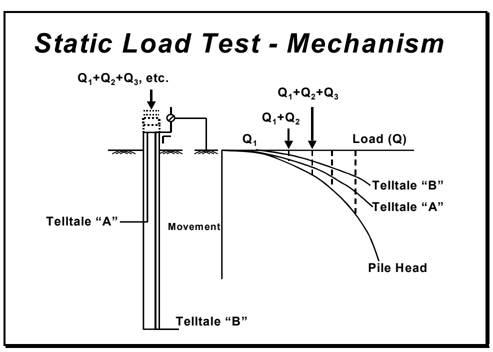
Schematic of a reaction pile setup for a load test.

Slide 9-3-10

Photo of a typical reaction pile setup for a static load test. Note that the time involved to mobilize equipment, drive test pile and reaction piles, build the frame, observe waiting period and run test can be great and represented a delay to the contractor.

Slide 9-3-11

Semi-funny slide about the use of water-filled barges for dead load reaction. Comment is that barges must be covered or wind can cause dangerous water shift that can destabilize barges.



Slide 9-3-12

The static load test involves application of load and measurements of pile movement. Although the test can be completed by measuring only deflection of the pile head, FHWA publications recommend using instruments called telltales to learn more information about transfer of load down the pile. Plots of load versus deflection are made to interpret the failure load and to estimate load transfer at telltale depths.

Dynamic Pile Testing
ASTM D4945

- ***Measures strain and pile acceleration to predict capacity***
- ***Requires experienced personnel to interpret results***
- ***Correlates well with static test results***
- ***Used for time-related capacity changes***

Slide 9-3-13

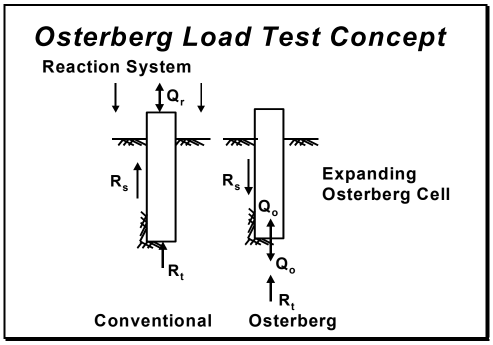
Overview dynamic testing features. Note that the method dates back to the 1970's and the standard was established in 1989. Mention both Pile Dynamic and TNO equipment available.

Slide 9-3-14

Note the strain gage and accelerometer are mounted on the pile during the driving operation. The energy that is delivered to the pile is measured by the instruments and compared to the rated energy of the hammer to evaluate system efficiency. Electrical cables are shown here to transmit the measurements to a field computer but new technology is available for wireless transmission of the signal to the computer.

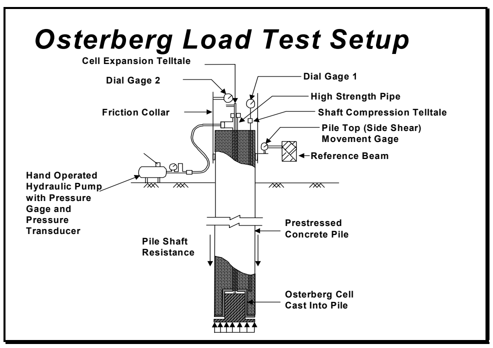
Slide 9-3-15

The dynamic measurements are fed to a small field computer where the data is recorded, processed and results displayed in real time for each hammer blow. The beauty of the system is that the results are available during the pile driving operation to permit the engineer to assess factors such as hammer performance, stresses in the pile, and pile capacity. Data may be collected during both initial driving and after a "setup" period to evaluate changes in pile capacity with time.



Slide 9-3-16

The Osterberg cell test uses a sacrificial load cell which is embedded at or near the tip of the foundation element. The cell is expanded to mobilize both the skin friction and the end bearing of the foundation. Unlike the static test, the Osterberg cell test does not require any external reaction load.

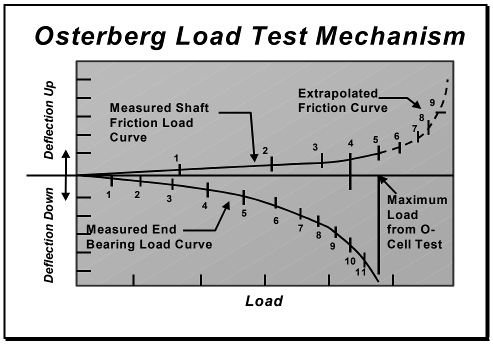


Slide 9-3-17

The Osterberg cell is a proprietary device. The test requires substantial instrumentation and equipment to monitor the response of the foundation to the applied load. The services of specialized load test professionals are needed to setup and run the test. Note that The Osterberg cell test is commonly used for drilled shafts but can also be used for piles.

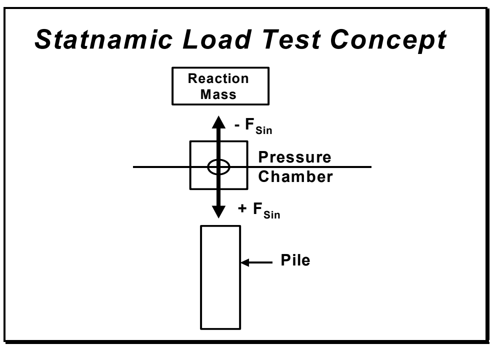

Slide 9-3-18

Example of placement of an Osterberg cell in a drilled shaft at the Boston Central Artery Project. This cell will be positioned 10’ above the base of the shaft to equalize predicted end bearing and skin friction forces. The rods below the cell are instrumented with strain gages to show the distribution of load in the socket below the cell.



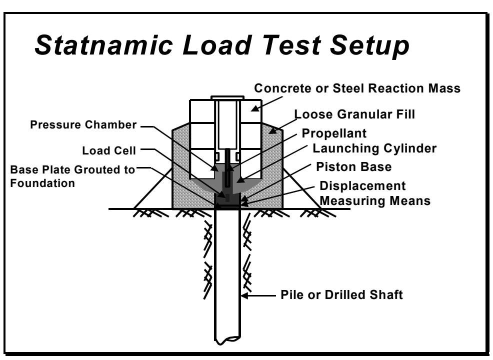
Slide 9-3-19

Osterberg cell test results are plotted on a split load-deflection graph with the skin friction and end bearing resistance shown separately. An important item to note is that the failure load is not achieved for both skin and end bearings during a single stage test. Special techniques, such as the use of cells at multiple locations, are available to refine the ultimate failure load.



Slide 9-3-20

The Statnamic test is a proprietary test method. The concept of the Statnamic test for vertical load capacity is based on a rapid application of load by burning solid fuel in a pressure chamber on top of the foundation. The foundation is accelerated downward.

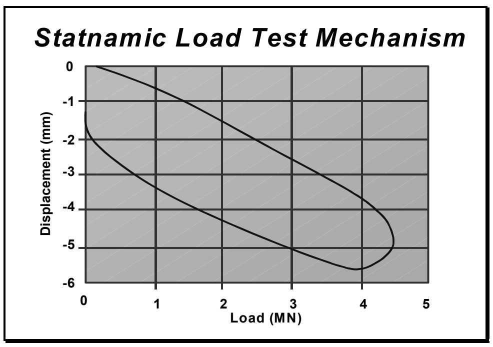


Slide 9-3-21

The setup and conduct of the Statnamic test requires load test specialist. The reaction load can be varied to permit a wide range of load application. The test can be assembled and conducted within minimal timeframes.

Slide 9-3-22

This picture shows the worker assembling the reaction load for Statnamic test. Note the concrete reaction doughnuts are being placed inside the retention structure and over the launching cylinder.



Slide 9-3-23

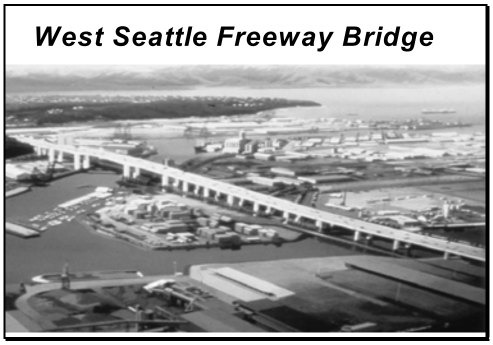
The data from a Statnamic test is plotted in the typical load-deflection manner for other load tests. However this data includes the effects of the rate of loading and the shaft inertia. Current interpretation procedures use the zero velocity point on the curve to eliminate load rate effects and then subtract the inertia load to find the ultimate static capacity. FHWA purchased a Statnamic device in 1999 for research into the test method and the data interpretation.

Examples of Cost Savings From Pile Load Testing

- ***West Seattle Freeway - Major Project Design Phase Program***
- ***North Carolina DOT - Coordinated Design Phase Programs***
- ***Oregon DOT - Routine Project Test Programs***

Slide 9-3-24

Overview savings, which were achieved by highway agencies, from load testing.



Slide 9-3-25

Case history of foundation savings due to load testing on a large project, the West Seattle Freeway, which crosses the Green River and Harbor Island. The bridge was about a mile long and cost about $100 million. The soils, which were generally silts and sands, varied in density and thickness with no bearing layer at a reasonable depth.

West Seattle Freeway Bridge Design

- ***Friction Piles for all Foundations***
  - *36" Diameter Open-end Pipe Piles for Main Channel Piers (24,000 LF driven)*
  - *24" Octagonal Prestressed Concrete Piles for Approach Piers (172,000 LF driven)*

Slide 9-3-26

Case history of savings on a large project, the West Seattle Freeway. The results of the load test permitted the main pier piles to be designed for a 600 ton load at lengths about 200'.

Slide 9-3-27

The project used both static and dynamic tests to measure pile capacity at several locations across the site. Note that the static test had extensive telltale instrumentation to permit load transfer measurements in each soil layer. These measurements were used in combination with the boring results at each pier to develop pile lengths for the 80 footing locations.

West Seattle Freeway Bridge

Item	Estimated Saving	Remarks
Piles	$ 9,000,000	-
Pile cap size	$ 1,000,000	-
Test pile data provided to bidders	?	Difficult to quantify savings

Slide 9-3-28

This design load test permitted an increase in the pile design load and therefore reductions in both the number of piles and the cap size. The saving was about 10% of the project cost. All the driving information was provided to the bidders to assist in their estimate of the foundation cost associated with installation of the piles.

North Carolina Design Phase Load Test Programs

Projects 1994-1999	Project Cost $ (Bid)	Test Cost $ (Bid)	Estimated Savings and (%)
Neuse River	92,998,000	310,000	10,500,000 (11)
New River	16,457,000	276,000	850,000 (5)
Chowan River	33,923,000	375,000	1,357,000 (4)
Oregon Inlet	122,800,000	1,155,000	1,200,000 (1)
Croatian Sound	88,963,000	998,000	1,800,000 (2)

Slide 9-3-29

North Carolina DOT published the results of their design phase load test programs in a TRB paper at the 79th meeting in January 1999. The results of the 5 load test programs are summarized above and show substantial savings. The % saving in the parenthesis in the last column is percent of the total project cost.

North Carolina Design Phase Load Test Programs

- ***Benefits to Project Design***
  - *Reduction in length*
  - *Increase in capacity*
  - *Reduced number of piles*
  - *Driveability, jetting, and set-up evaluated*
  - *Improved special provisions*

Slide 9-3-30

In addition to tabulating the cost savings, the DOT quantified the benefits in terms of improvements to general project design features. Important to note that some improvements benefited future designs.

North Carolina Design Phase Load Test Programs

- **Benefits to Project Construction**
  - Improved special provisions
  - Restructured pay items
  - Eliminated unsatisfactory alternates
  - Established dynamic test criteria
  - Established pile equipment requirements
  - Reduced potential claims

Slide 9-3-31

The DOT also quantified the benefits of the test programs to project construction. Again some of the improvements had long term implications.

North Carolina Design Phase Load Test Programs

- **Benefits of new technology verified….**
  - Pile driving analyser
  - Osterberg cell axial test
  - Statnamic axial & lateral test
  - Integrity test procedures

….and applied to reduce the costs of subsequent test programs

Slide 9-3-32

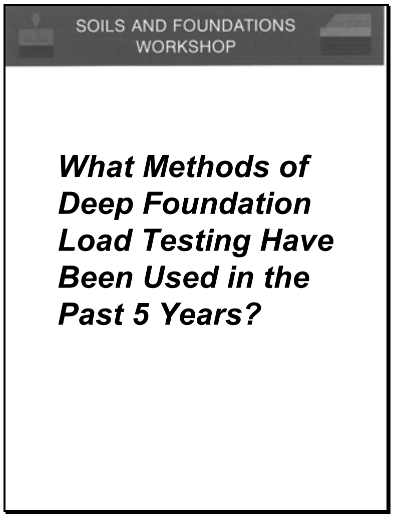
Lastly the DOT decided to independently verify the benefits of new technology in pile load testing in their design phase test programs. New methods were used in conjunction with proven methods to benchmark the performance of the new methods. The DOT developed sufficient confidence in the new methods to be able to apply the new technology independently to subsequent projects; thereby saving time and money in the load testing without sacrificing quality.

Cost Savings for Oregon DOT from Small Project Pile Load Tests

Bridge Location	Pile Size & Type	Length Reduction	Net Savings	Piling Saving
Denny Rd.	12” Sq. Precast Concrete 30’	10’	$55,000	26%
Allen Blvd	12” Sq. Precast Concrete 30’	10’	$60,000	20%
Airport Rd	12¾” Closed end steel pipe 98’	30’	$135,000	25%

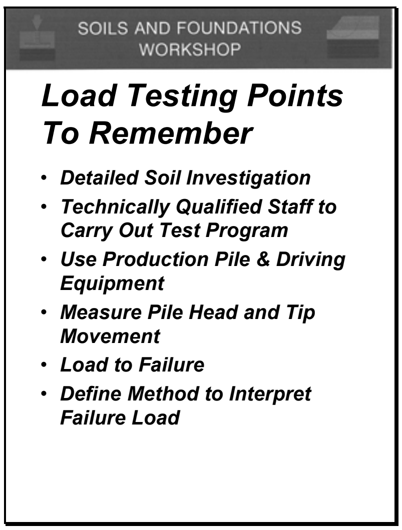
Slide 9-3-33

Oregon DOT demonstrated that a static load test program can be cost-effective on moderately loaded pile types. The total cost of the bridges on these projects were in the $2 million to $4 million range. The savings shown here are as a percentage of the foundation cost.



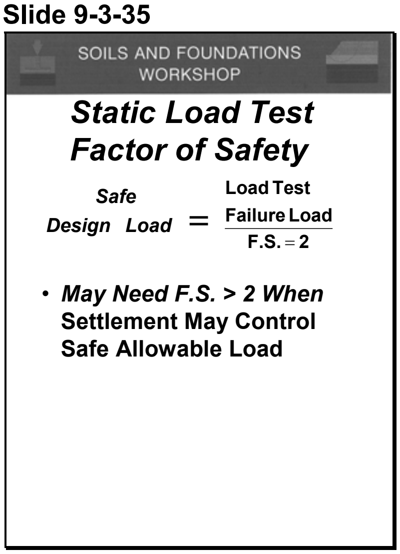
Slide 9-3-34

Instructor lists the answers from the question on a flip chart and discusses how the agency has used load tests (pre-design, construction tests loaded to failure, or construction tests to verify design capacity). This flip chart sheet will be referred to later to ask students questions about their practice for determining when to use, how to interpret failure load, and what safety factor to use in design or how pile lengths are revised in construction based on results.



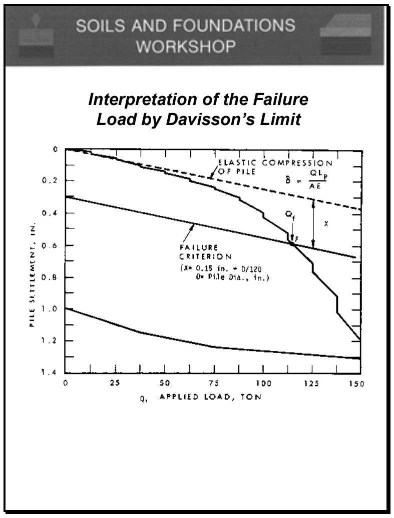
Slide 9-3-35

Show guidelines for load testing. Remind students that these guidelines apply to all types of load testing. Load testing should never be considered a substitute for an adequate site investigation.



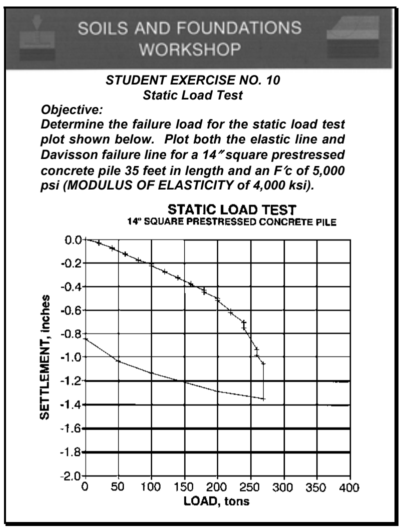
Slide 9-3-36

Instructor returns to previous flip chart sheet and ask group what safety factor is used for each test type shown. Then fill in the missing types covered in the lecture and ask what is the recommended safety factor. Then ask about the safety factor for the case of no testing and just using a formula or wave equation. Ask students to turn to the section in the reference manual for load testing and refer to the subsections on safety factor and the rule of thumb for cost effective testing.



Slide 9-3-37

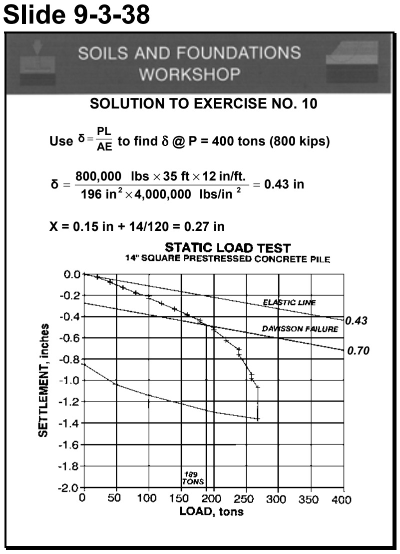
Ask student to turn to the reference manual section on Davisson's method and explain the procedure to find the interpreted failure load by Davisson's method. Mention that they will get a chance to try this method in a student exercise.



Slide 9-3-38

Student exercise to find the failure load by Davisson's method. Purpose of exercise is to learn the necessary data and procedure, which can be used to estimate failure load from a load test. Prepare a flip chart sheet with a rough plot of the load-settlement curve. Then select a group to put up the answer. Ask the remaining groups to refigure the failure load if the criteria was 0.05 inches per ton slope or simply a deflection of 5% of the tip dimension. Then compare results and point out the need to establish the method to interpret failure load; particularly in design-build contracts where the test may serve as the acceptance criteria.

Please refer to the end of the lesson for this exercise.



Slide 9-3-39

Use the overhead as necessary to explain answers to questions about the Davisson method and to show alternate failure interpretation methods. Demonstrate to the group how the length of the pile is affected based on the test results. Relate the change in length to cost in both materials and installation.

Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

CONSTRUCTION CONTROL
Pile Load Testing

1. ***Relate pile load testing to design goals and cost savings***
2. ***Interpret pile failure load***

Activity: Question-answer
Davisson's Method

Slide 9-3-40

Repeat objectives for load testing session prior to moving on to the Apple Freeway for the deep foundation lesson closure.

At the instructor's option, the GLRWEAP software may be demonstrated.

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

Pile Design

Construction Aspects

Instrumentation
Wave Equation
Hammer Approval

Slide 9-3-41

Show progress of Apple Freeway design and test students on selected information learned in the deep foundations lesson. Remember that the instrumentation information was covered earlier in the session.

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

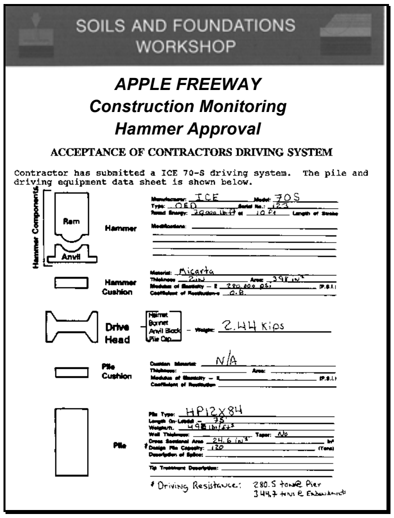
Design Check of Driveability of 12 X 84 H-pile

SUMMARY OF GRLWEAP RESULTS FOR HP12X84 (DELMAG 30-13)

Rut (kips)	Bl Ct (bpf)	Stroke (ft) down	up	min Str (ksi)	i,t	max Str (ksi)	i,t	ENTHRU (kip-ft)	Bl Rt (b/min)
350.0	32.9	6.83	6.70	.00	(1, 0)	29.09	(4, 5)	25.9	45.3
550.0	79.6	7.38	7.32	.00	(1, 0)	31.53	(3, 5)	26.3	43.5
631.8	114.8	7.66	7.44	.00	(1, 0)	32.67	(2, 4)	26.9	42.9
689.4	170.6	7.51	7.47	.00	(1, 0)	32.46	(2, 5)	26.3	43.1
740.0	256.7	7.44	7.49	.00	(1, 0)	32.19	(2, 5)	25.9	43.2

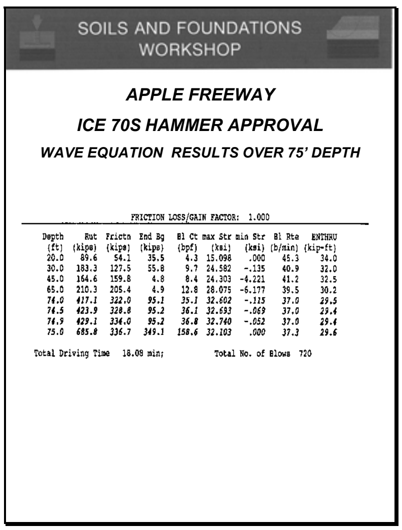
Slide 9-3-42

Ask students to comment on driveability of Apple Freeway H-pile based on current project knowledge and wave output information shown in the overhead of the wave equation output for the maximum pile load.



Slide 9-3-43

Ask students to comment on acceptability of the hammer submitted by the Apple Freeway contractor. First ask what items on this form should be checked (answer is energy if maximum or minimum was specified, type of hammer cushion should be manufactured material, pile cushion if required should be a minimum of 4" thick, pile length and type should match the contract criteria).



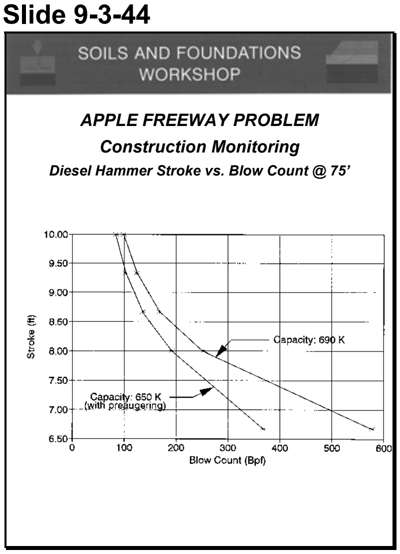
FRICTION LOSS/GAIN FACTOR: 1.000

Depth (ft)	Rut (kips)	Frictn (kips)	End Bg (kips)	Bl Ct (bpf)	max Str (ksi)	min Str (ksi)	Bl Rte (b/min)	ENTHRU (kip-ft)
20.0	89.6	54.1	35.5	4.3	15.098	.000	45.3	34.0
30.0	183.3	127.5	55.8	9.7	24.582	-.135	40.9	32.0
45.0	164.6	159.8	4.8	8.4	24.303	-4.221	41.2	32.5
65.0	210.3	205.4	4.9	12.8	28.075	-6.177	39.5	30.2
74.0	*417.1*	*322.0*	*95.1*	*35.1*	*32.602*	*-.115*	*37.0*	*29.5*
74.5	*423.9*	*328.8*	*95.2*	*36.1*	*32.693*	*-.069*	*37.0*	*29.4*
74.9	*429.1*	*334.0*	*95.2*	*36.8*	*32.740*	*-.052*	*37.0*	*29.4*
75.0	*685.8*	*336.7*	*349.1*	*158.6*	*32.103*	*.000*	*37.3*	*29.6*

Total Driving Time 18.08 min; Total No. of Blows 720

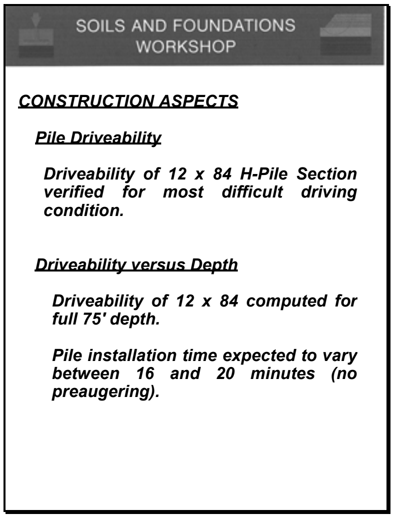
Slide 9-3-44

The second part of the hammer approval process is to determine if the hammer can drive the pile to the estimated length and driving capacity without damage. Ask the students to examine the wave summary and determine if this hammer is acceptable (answer is yes although this is a borderline case. The stresses are near the maximum as is the blow count but only for the last foot of driving. Also this is the most difficult driving condition for all footings on the structure. Need to inform the inspector not to overdrive the pile when rock is reached).



Slide 9-3-45

Ask students how they would interpret this information to determine if a pile was acceptable (answer is to obtain a combination of blow count and stroke within 5' of the estimated length that meets the driving capacity requirement).



Slide 9-3-46

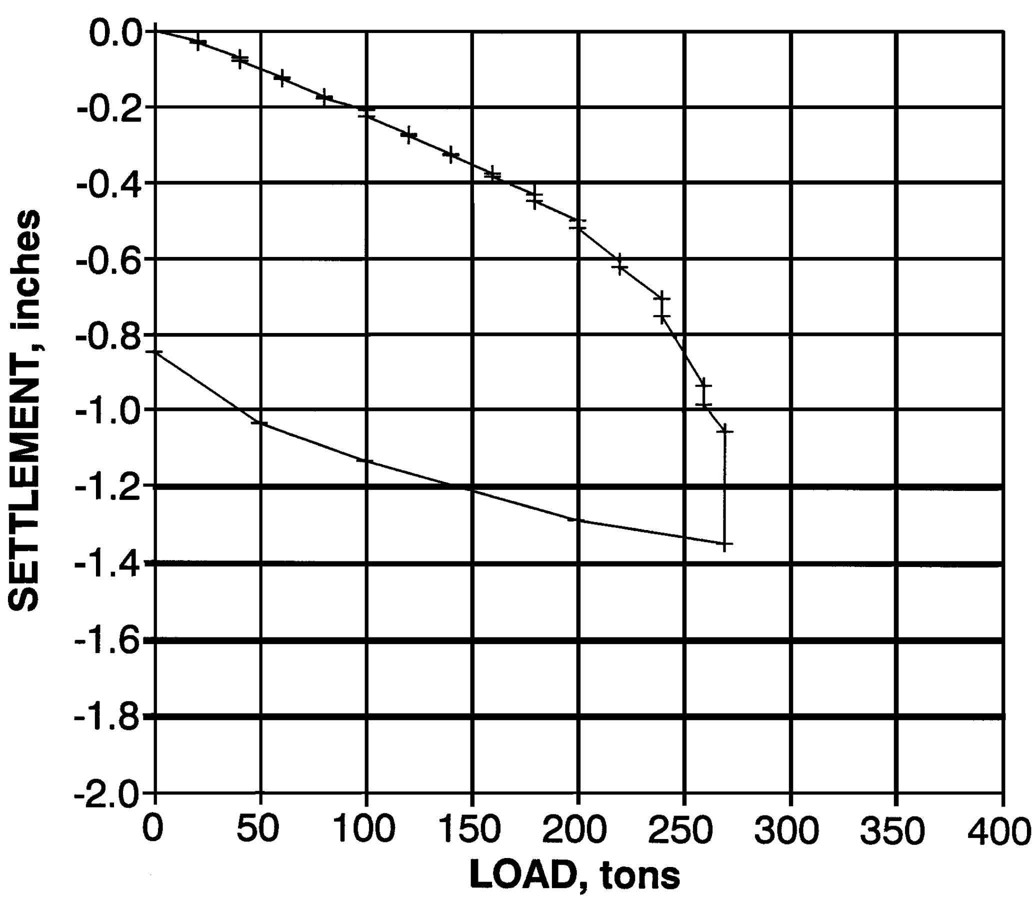
Review what information was developed for construction portion of the Apple Freeway.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 10
Static Load Test

Objective:
Determine the failure load for the static load test plot shown below. Plot both the elastic line and Davisson failure line for a 14″ square prestressed concrete pile 35 feet in length and an F′c of 5,000 psi (MODULUS OF ELASTICITY of 4,000 ksi).

STATIC LOAD TEST
14" SQUARE PRESTRESSED CONCRETE PILE



SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 10

Use $\delta = \frac{PL}{AE}$ to find δ @ P = 400 tons (800 kips)

$$\delta = \frac{800{,}000 \text{ lbs} \times 35 \text{ ft} \times 12 \text{ in/ft.}}{196 \text{ in}^2 \times 4{,}000{,}000 \text{ lbs/in}^2} = 0.43 \text{ in}$$

X = 0.15 in + 14/120 = 0.27 in